APPLICATION OF MARSHALL METHOD IN HOT MIX DESIGN

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This is an advance copy of a paper to be presented at the Sixty-Second Annual Meeting of the American Society for Testing Materials (1916 Race St., Philadelphia 3, Pa.) to be held in Atlantic City, N. J., June 21-26. This advance copy is primarily to stimulate discussion. Discussion is invited and may be transmitted to the Executive Secretary. The paper is subject to modification and is not to be published as a whole or in part pending its release by the Society through the Executive Secretary.

TABLE II

FIRST COOPERATIVE TEST RESULTS

Laboratory Marshall Test Properties	A	B	C	D	E	F	G	Mean Value $\overline{X}$	Standard Deviation Expressed as % of $\overline{X}$*
Specific Gravity	2.29	2.30	2.29	2.33	2.30	2.31	2.31	2.30	0.65
Stability @140°F	1288	1405	1548	1625	1243	1158	1028	1328	16.0
Flow 1/100 in.	8	6	11	15	11	12	12	11	26.7
Percent Deviation from mean for Stability**	+3.0	-5.8	-16.6	-22.4	+6.4	+12.8	+22.6	–	–

* Standard Deviation $= \left[\frac{n(x_1^2 + x_2^2 + --- x_n^2) - (x_1 + x_2 + --- x_n)^2}{n(n-1)}\right]^{1/2}$

where: $x_1, x_2, --- x_n$ = Individual results
n = Number of test results

Standard deviation expressed as percent of $\overline{X} = 100\frac{*S}{\overline{X}}$

** Percent Deviation from mean $= \frac{(x_i - \overline{X})100}{\overline{X}}$

where: x_i = Individual results $x_1, x_2 --- x_n$, etc.
$\overline{X}$ = Arithmetic Mean of x_i

2) Rate of cooling of briquets during testing when taken out of the 140°F bath.
3) a) Effects of variations in testing temperature on stability values.
   b) Mixing temperature on specific gravity and stability.
   c) Compaction temperature on specific gravity and stability.

Table III shows the time required for a briquet to attain the testing temperature of 140°F. Thirteen minutes is required for the center of the briquet to be raised to 140°F from an original temperature of 50°F. Consequently, it was decided that a 20 minute period in the bath was sufficient, prior to testing.

The rate of cooling of a specimen when removed from the 140°F bath is affected by temperature of breaking heads. In this study breaking head temperatures were varied from 25°F to 140°F. Temperatures inside the briquet were measured at two points - one in the center, another approximately 1/2 in. from the side of the briquet. These results are given in Table IV. There is a considerable drop in the briquet side temperatures for all head temperatures with the exception of 140°F. As the original head temperature is reduced the rate of cooling is increased. Figure 1 shows stability values as affected by testing temperature. Since Marshall stability is highly affected by the viscosity of the asphalt at the time of testing, minute variations in viscosity or temperature - will definitely cause fluctuations in results. The same condition is observed when the grade or penetration of asphalt is changed, resulting in a higher or lower viscosity at the testing temperature. In Figure 1, an appreciable affect is noted on stability at temperatures below 140°F, diminishes at temperatures above 140°F. Thus, closer control of temperature by heating the breaking heads to 140°F is necessary to obtain better reproducibility of results and testing should be accomplished in less than one minute.

The study of the effects of mixing and compaction temperatures on Marshall stability and specific gravity, yielded some very interesting data which needs detailed discussion. This problem will be analyzed in detail later. The indications of this phenomina led to the belief that temperature is one of the most important factors and that it should be regarded as such in sample preparation and testing using this method. A second cooperative test was then conducted after making numerous changes in design procedure with particular emphasis on temperature control. These included:

1) Heating the compaction molds and breaking heads to 140°F.
2) Using electric ovens with mercury bulb thermometers for heating the aggregate.
3) Specifying exact mixing temperatures rather than limits with tolerances.

Results of the second test are shown in Table V. The standard deviation is 7.3 percent, a reduction of approximately 100 percent from the first test. Each individual dispersion about the mean also shows a remarkable reduction, with the exception of Laboratory F which used gas ovens. Laboratory D, although showing considerable improvement still had a larger dispersion than the rest. In this particular case, the asphalt was heated overnight at 280°F which may be the major cause for such a large dispersion.

Specific gravity values did not show too great a variation in deviation in both tests conducted, although they did show a reduction of 0.13 percent deviation from the first test.

TABLE III

HEATING BRIQUETS IN BATH AT 140°F

Original Temperature - Deg. Fahr.	50	72
Time - Minute	Temperature of Briquet - Deg. Fahr.	
1	55	78
2	76	90
3	93	105
4	107	115
5	118	124
6	124	129
7	130	133
8	134	136
9	136	139
10	137	140
11	139	140
12	140	140
13	140	140
20	140	140

TABLE V

SECOND COOPERATIVE TEST RESULTS

Laboratory Marshall Test Properties	A	B	C	D	E	F	G	Mean Value $\overline{X}$	Standard Deviation Expressed as % of $\overline{X}$
Specific Gravity	2.29	2.28	2.31	2.30	2.31	2.31	2.31	2.30	0.52
Stability @140°F	1165	1135	1198	1248	1140	1000	1190	1158	7.3
Flow 1/100 in.	9	7	12	11	11	10	8	10	18.4
% Deviation from the Mean for Stability	-0.6	+2.0	-3.5	-10.5	+1.6	+13.6	-2.8	–	–

Such factors as temperature of mixing, compaction, forming molds, breaking head and mode of heating do have appreciable affects on the reproducibility of results. Consequently, the test method, then in use in Louisiana, was modified to include and stress temperature requirements. This method, in its entirety, is given in the Appendix.

Mixing Viscosity of Asphalt and Marshall Properties

In the preceding discussion, it was mentioned that factors which affect reproducibility of results included mixing temperature. "The Marshall Method for the Design and Control of Bituminous Paving Mixtures"(1) specifies a temperature range of 340 - 370°F for mixing aggregate and asphalt without making any provisions for consistency of the asphalt used in the mixture. Similarly, ASTM Designation 1559-58T, "Tentative Method of Test for Resistance to Plastic Flow of Bituminous Mixtures by Means of the Marshall Apparatus", requires that the mixing be done at 300±5°F. In other words, for all grades of asphalt, these temperature ranges can be employed for mixing purposes. These recommendations may be adequate for mixing and compaction of certain asphalts. Viscosity - which is directly related to temperature - would seem a more favorable criterion, and is likely to permit more uniform results. Mixing viscosity - or viscosity of asphalt at the temperature at which it is being mixed - has a direct bearing on stability of mixtures. It has also been established that compaction viscosity - viscosity of asphalt at the temperature it is being compacted - has measurable effects on stability.

In order to have a better understanding of viscosity-stability relationship, it is necessary, first, to briefly show the affects of temperature on viscosity for different grades of asphalt. The curves, given in Figure 2, define such a relationship for three grades of asphalt - 62, 87 and 137 penetration. All three are from the same crude and refinery. A wide difference is noted between viscosities of different grades of asphalt at lower temperatures. This difference diminishes at elevated temperatures. For instance, at 325°F viscosity for 62 penetration asphalt is 85 seconds Saybolt-Furol (SSF), for 87 penetration it is 68 SSF, and for 137 penetration asphalt it is 53 SSF.

Figure 3 defines mixing temperature-stability relationship for the same asphalts discussed in the preceding paragraph. Each curve has a peak and a trough at different temperatures. For example, curve for 62 penetration asphalt has its peak at 325°F, 87 penetration at 315°F and 137 at 300°F. In other words, as the asphalt gets softer, the temperature of the peak decreases. Each peak was assumed to be the "optimum mixing temperature" for the corresponding asphalt.

Additional study of Figures 2 and 3 will reveal that, even though the optimum mixing temperature is different for each one of these asphalts, the corresponding viscosities of all are 85 SSF.

Figure 4 shows the Marshall stability-mixing viscosity relationship and general trend of all three curves is the same. Curve for 62 penetration asphalt shows a low stability value of 1030 lb. at 580 SSF, at a corresponding temperature of 250°F. This value gradually increases with decreasing viscosity - increasing temperature - reaching a peak value of 1230 lb. at a viscosity of 85 SSF (325°F). From there on stability remains constant for a 30 SSF range and, then again, starts to ascend to a maximum value of 1420 pounds at 25 SSF (400°F).

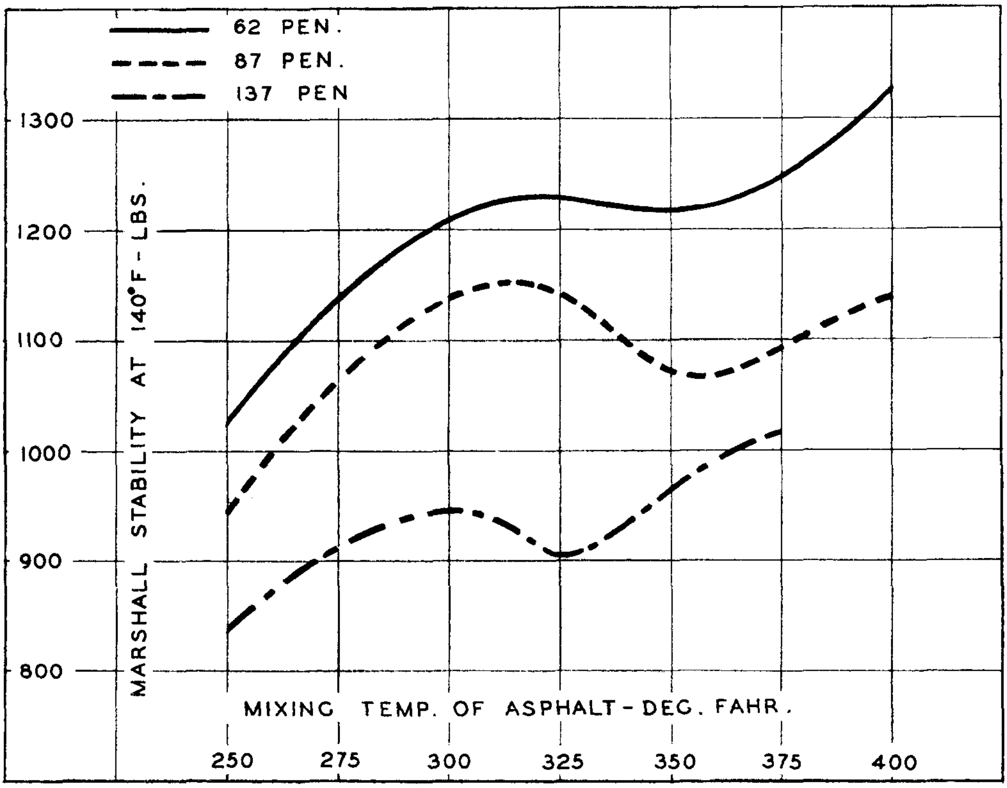

Figure 3 – Relationship of Mixing Temperatures of Asphalt-Marshall Stability at 140°F of Laboratory Prepared Specimens.

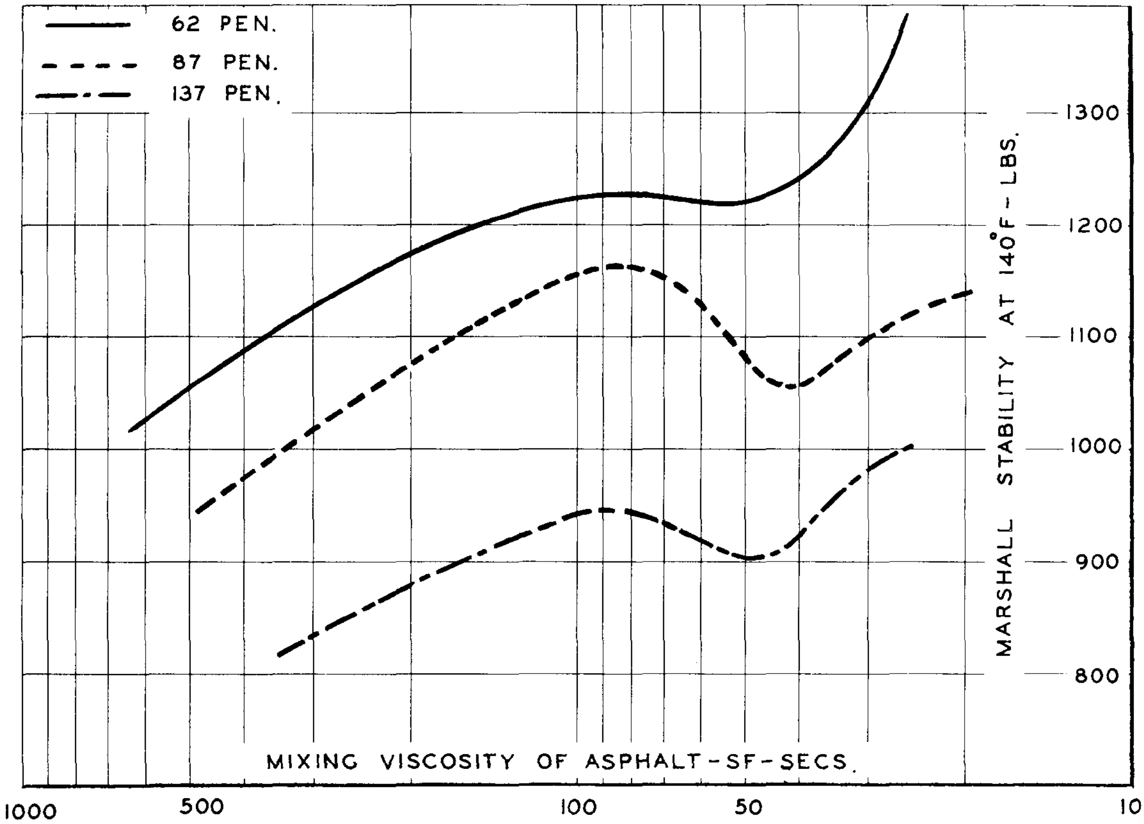

Figure 4 – Relationship of Mixing Viscosity-Marshall Stability at 140°F at Laboratory Prepared Specimens.

The curve for 87 penetration asphalt also defines the same relationship reaching a peak value of 1160 lb. at 85 SSF and from this point instead of remaining constant, as in the first case, drops to 1060 lb. at 45 SSF and again suddenly starts increasing to attain a value of 1135 lb. at 20 SSF.

The last curve - 137 penetration asphalt - also shows identical relationship between mixing viscosity and Marshall stability with a peak at 85 SSF, a drop from the peak at 45 SSF. Thus we see that in all three curves, the peak and inversion point occur at practically the same viscosity.

The above relationship shows that intimate coating, correct film thickness and a uniform dispersion are not achieved until aggregate and asphalt temperatures are high enough to permit droplets of bitumen to envelope particles of aggregate upon contact. In order to rapidly wet the aggregate, bitumen must flow freely or be in a state of low viscosity. At high viscosity values, with corresponding low temperatures, this intimate coating is not achieved, until such a point where fluidity reaches an ideal state to coat the aggregate particles thoroughly and properly, to insure good bondage. Further rise in temperature makes the asphalt extremely fluid and attain such a state that, instead of coating the particles, to obtain a uniform thickness to insure proper bondage, it merely lubricates the particles causing excessive movement under dynamic impact of hammer, thereby giving mal-orientation. This results in a drop in stability from the peak. Further rise in stability from there on could very well be attributed to the hardening or oxidizing of asphalt which results in a change in consistency.

Movement of the particles due to a low viscosity during compaction is not the only factor that affects stability. Even though samples are compacted at a constant temperature but mixed at different temperatures - or viscosities - the results will be affected. Figure 5 shows effects of mixing viscosity on stability when compaction temperature is kept constant, at 275°F, for an 85-100 penetration grade asphalt and the peak for stability curve is again at a viscosity of 85 SSF. However, the extent of effects of variations in mixing viscosities are not as great as both the mixing and compaction viscosities, shown in Figure 5. Results show that regardless of the compaction temperature, Marshall stability is greatly affected by mixing viscosity. Likewise, compaction temperatures affect stability of the mixing temperature is kept constant. Effects of mixing viscosity on percent of theoretical gravity is also shown in the same figure and again defines the same relationship as stability-viscosity.

Discussions given so far were limited to only laboratory mixed samples. In an effort to confirm the results obtained in the laboratory, with those mixed at a hot mix plant under actual construction procedures, another study was made. In this case, hot mix samples were taken from trucks at regular intervals, compacted and tested. The relations obtained are shown in Figure 6. These are mixing viscosity versus: stability, percent of theoretical gravity of briquets and percent of theoretical gravity of the same mixture in the pavement after rolling (roadway density) under a controlled compactive effort. It will be interesting to note that in this case, too, the peak and the trough occur at 85 SSF and 45 SSF, respectively, for all three relationships.

Close control of the resistance of pavement to plastic deformation at maximum road temperatures - i. e., tendency to rut, shove, or otherwise displace under traffic - is essential for satisfactory performance. Whether any of the aforementioned properties (rutting, shoving, etc.) are appreciably affected under traffic by mixing viscosity remains to be studied in these series of investigations. However, data collected so far from one of our recent research projects,

TABLE VI

LABORATORY MIXING VERSUS PLANT MIXING

Plant No.	1			2			3			4			5			6		
Method of Mixing	Plant	Hand	Mixer	Plant	Hand	Mixer	Plant	Hand	Mixer	Plant	Hand	Mixer	Plant	Hand	Mixer	Plant	Hand	Mixer
Specific Gravity	2.33	2.32	2.31	2.37	2.36	2.35	2.35	2.32	2.31	2.35	2.31	2.32	2.34	2.32	2.28	2.35	2.31	2.32
% V.F.A.	65.5	63.8	62.2	79.4	77.1	74.9	79.2	72.9	71.2	82.0	74.2	76.0	78.3	73.8	66.7	76.8	68.9	70.9
Stability @140°F	1335	1360	1350	1210	1210	1125	1245	1360	1070	1135	1020	840	958	910	783	1230	965	1020
Flow 1/100 in.	9	8	8	10	8	8	11	7	10	10	10	9	10	6	10	8	6	8
Mixing Temp. F.	283	325	325	324	300	300	294	325	325	279	300	300	259	300	300	302	300	300
A. C. Content – %	4.7	4.7	4.7	4.8	4.8	4.8	5.5	5.5	5.5	5.7	5.7	5.7	5.2	5.2	5.2	5.0	5.0	5.0

construction in addition to conventional steel wheel rolling. Louisiana Specifications have been requiring use of these rollers since 1958. Results obtained have been most favorable and is believed will increase pavement life by considerable reductions in rutting and ravelling. When a change is made in compactive effort in the field, it may require a similar change in the laboratory. A comparison of four different rolling methods is made in Figure 8, as based on - laboratory compaction - 50 blows on each face. The control section, where only conventional steel wheel rollers were used, shows an original density of 96.0 percent of laboratory compaction. The curve identified as nine passes of pneumatic roller, (1) in addition to steel wheel rolling, shows 96.6 percent. Thirteen passes of pneumatic rolling gives 97.2 percent and 15 passes 97.7 percent. After eight months of traffic - classified as average heavy in Louisiana - 15 passes show approximately 99.6 percent laboratory density whereas steel wheel rolling is only 99.0 percent - an increase of 2.0 percent for the former and 3.0 percent for the latter. In a similar manner the rate of increase of rutting was less for 15 passes. In nine months the rate of increase of density diminishes, and shows a very slight increase thereafter. Since roadway density has not reached or gone beyond the laboratory density so far and has more or less levelled off, it may tentatively be concluded that this compactive effort - 15 passes (7-1/2 coverages), 2000 lb. per wheel and 55 psi pressure - will not require any drastic changes in laboratory compaction. Most projects constructed in Louisiana, to date, have reacted very favorably and need of an increase in compactive effort has not arisen. Since, such an increase will reduce the design asphalt content, it should not be made unless absolutely required by extremely heavy traffic conditions. This problem will further be studied under heavier traffic conditions and with different mixtures before final conclusions can be drawn.

Recommended Criteria

The data presented in this paper is insufficient to evaluate the effects of mixing and possibly rolling viscosities on the performance of pavements on an extended basis, nevertheless, it is sufficient to justify a limited statement. In our opinion, all factors that affect the density, to which a suitable mix can be rolled during construction, have a direct bearing on the performance of hot mix pavements. Sand and gravel hot mixtures especially require high densities and the rutting is very much affected by the original roadway density. Therefore, the mixing viscosity should have a bearing on the performance of sand and gravel aggregate, hot mix pavements.

In specifying mixing temperatures, viscosity should be of primary importance. Certainly oxidation, during mixing, is an important factor to consider. Nevertheless, the present day traffic requires highly stable mixtures resistant to rutting. In Louisiana excessive rutting has been found to be a problem of a more serious concern than deterioration due to oxidation. Even at the risk of oxidation, the measures that minimize rutting had to be taken. These consisted of using viscosities to specify mixing temperatures, three wheel rolling and pneumatic rolling and using these same temperatures in Marshall design, and inclusion of pneumatic rolling for compaction in addition to conventional means.

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(1) The pneumatic rolling was done by use of a 9-ton roller, 2000 lb. on each wheel, 55 psi tire pressure at a mix temperature of 190 – 225°F.

Our experience with the Marshall Method, modified as previously explained, has once again confirmed the general opinion that it is affected by the viscosity of asphalt and that it is mostly a measure of cohesion. In our opinion, the best practical means of evaluating asphalt coating characteristics is a cohesion test. Visual inspection and even a microscopic analysis of film thickness does not seem to be as effective, as they indicate only the uniformity of asphalt film. A cohesion test, however, would evaluate the sufficiency of the film thickness, also. In addition to designing mixtures, Marshall Method, in this respect, would be a valuable tool.

Roadway density requirements should be specified as a factor of laboratory density, such as 98 percent of laboratory briquet specific gravity. A second requirement should also be included in specifications, based on the theoretical specific gravity of the mixture, to eliminate any errors that might be induced by a low compaction temperature of the briquet to be used to check the roadway density.

The criteria being used in Louisiana for the past six years have been found satisfactory and given excellent results with sand and gravel hot mixtures. This is very similar to the one devised by U. S. Corps of Engineers at Waterways Experimental Station for 100 psi tires. Only the stability and flow requirements were modified as follows:

Blended aggregates showing a water absorption of less than 2. 5 percent.

For through and light traffic. For plant mixed samples.

	Binder Course	Wearing Course
Theoretical Gravity, %	94 - 96	95 - 97
Voids - Total Mix, %	4 - 6	3 - 5
Voids Filled with Bitumen, %	65 - 75	75 - 85
Marshall Stability @140°F - lb.	1000 min.	1000 min.
Flow 1/100 in.	8 - 18	8 - 18

Note: The specific gravity of the aggregate will be determined by use of LDH Designation: TR-300, "Apparent Specific Gravity of Coarse Aggregate for Bituminous Mixtures," and LDH Designation: TR-301, "Apparent Specific Gravity of the Fine Aggregate and Mineral Filler for Bituminous Mixtures".

For starting, stopping and city traffic.

	Binder Course	Wearing Course
Theoretical Gravity, %	94 - 96	95 - 97
Voids - Total Mix, %	4 - 6	3 - 5
Voids Filled with Bitumen, %	65 - 75	75 - 85
Marshall Stability @140°F - lb.	1000 min.	1000 min.
Flow 1/100 in.	8 - 18	8 - 18

Note: The specific gravity of the aggregate will be determined by use of LDH Designation: TR-300 and TR-301.

In very few instances it was deemed necessary to reduce the minimum requirement for percent voids filled with asphalt by 5 percent due to slight flushing of fines and asphalt to the surface of the pavement when pneumatic rollers were used.

Other factors that reduce the stability, not discussed in this paper, include presence of moisture in the aggregate when dried at hot mix plants and a presence of small quantities of fuel oil in the aggregate due to improper combustion when fuel oil is used in drying aggregates.

Presence of varying degrees of moisture in the aggregate will result in fluctuations in stability values - with higher moisture contents the reduction will be greater. Fuel oil in the same manner will affect the results.

Conclusions

The data and discussions presented are sufficient to draw some definite and several tentative conclusions.

Regarding the reproducibility of test results, it can definitely be stated that, 1) the experience of the operator affects the results whenever hand mix--ing is used, 2) the mechanical mixer does improve repeatability for the same operator but has shown a tendency to give slightly lower results for stability and specific gravity, 3) heating the breaking heads to 140°F in the water bath does improve test results and should be given due consideration, 4) the viscosity of asphalt, at the time of mixing and compaction of laboratory samples, have pronounced affects on test results. Plant mixed and pavement cores show the same tendency. Therefore, all factors that affect the temperature of mixing will have a bearing on laboratory results. Electric ovens have given very desirable results and are recommended for use.

Rutting of a pavement under traffic seems to be affected by density and mixing viscosity.

Specific gravity of samples mixed at a plant have consistently shown higher results than those mixed in the laboratory. This affects the optimum asphalt content as obtained in the laboratory. Further tests are under way to establish causes of this discrepancy. In the meantime, it is necessary to use two separate criteria - one for mix design and another for plant control.

The density obtained by 50 blows of the hammer - on each face of the sample seems to be satisfactory for use with pneumatic roller. The study is not complete, and at the present time, definite conclusions should not be drawn. However, the rate of increase of density so far indicates that it is unlikely that a change in the number of blows be necessitated for present day traffic.

In conclusion, it can be stated that, even though more research is needed in the correlation of laboratory mixing with pugmill mixing, repeatability of results in using the Marshall Method can be improved by taking several precautionary measures. The results are highly affected by viscosity of the asphalt and the same condition is seen in pavements. The apparatus is simple, portable and inexpensive and the test method is very practical and rapid. Considering the conditions encountered in the field and necessity of quick measurements, the Marshall Method is certainly a very valuable tool in hot mix design and control.

APPENDIX

TABLE VII

BIN PROPORTIONS AND THEORETICAL GRADATION OF AGGREGATE FOR REPRODUCIBILITY TESTS BETWEEN OPERATORS

				Specific Gravity
Bin No. 1	Fine	51.9	Percent	2.66
Bin No. 2	Intermediate	20.8	Percent	2.64
Bin No. 3	Medium	11.3	Percent	2.62
Bin No. 4	Coarse	4.7	Percent	2.61
Mineral Filler	Limestone Dust	5.6	Percent	2.84
Asphalt Content	85-100 Penetration	5.7	Percent	1.02

Theoretical Gradation:

U. S. Sieve	Percent Passing
3/4 inch	100.0
1/2 inch	95.0
3/8 inch	83.0
No. 4	61.0
No. 10	59.4
No. 40	33.8
No. 80	19.7
No. 200	12.2

TABLE VIII

BIN PROPORTIONS AND THEORETICAL GRADATION OF AGGREGATE FOR MIXING VISCOSITY MARSHALL STABILITY TESTS AT DIFFERENT COMPACTION TEMPERATURES

				Specific Gravity
Bin No. 1	Fine	65.0	Percent	2.64
Bin No. 2	Intermediate	15.0	Percent	2.64
Bin No. 3	Medium	10.0	Percent	2.61
Bin No. 4	Coarse	6.0	Percent	2.60
Mineral Filler	Limestone Dust	4.0	Percent	2.71
Asphalt Content		6.0	Percent	

Theoretical Gradation:

U. S. Sieve	Percent Passing
3/4 inch	100.0
1/2 inch	94.0
3/8 inch	80.0
No. 4	67.7
No. 10	46.9
No. 40	23.3
No. 80	14.0
No. 200	9.3

TABLE IX

BIN PROPORTIONS AND GRADATION OF EXTRACTED AGGREGATE FOR RESULTS GIVEN IN TABLE VI

		Plant No. 1		Specific Gravity
Bin No. 1	Fine	45	Percent	2.634
Bin No. 2	Intermediate	18	Percent	2.638
Bin No. 3	Medium	16	Percent	2.630
Bin No. 4	Coarse	18	Percent	2.615
Mineral Filler	Silica Dust	3	Percent	2.679
Asphalt Content	60-70 Penetration	4.7	Percent	1.030

Gradation of the Extracted Aggregate:

U. S. Sieve	Percent Passing
3/4 inch	100.0
1/2 inch	81.0
3/8 inch	74.0
No. 4	47.0
No. 10	37.0
No. 40	21.0
No. 80	11.0
No. 200	5.0

TABLE X

BIN PROPORTIONS AND GRADATION OF EXTRACTED AGGREGATE FOR RESULTS GIVEN IN TABLE VI

		Plant No. 2		Specific Gravity
Bin No. 1	Fine	53.0	Percent	2.628
Bin No. 2	Intermediate	28.0	Percent	2.630
Bin No. 3	Coarse	15.0	Percent	2.612
Mineral Filler	Limestone Dust	4.0	Percent	2.697
Asphalt Content	85-100 Penetration	4.8	Percent	1.020

Gradation of the Extracted Aggregate

U. S. Sieve	Percent Passing
3/4 inch	100.0
1/2 inch	97.0
3/8 inch	93.0
No. 4	70.0
No. 10	55.0
No. 40	31.0
No. 80	16.0
No. 200	9.0

TABLE XI

BIN PROPORTIONS AND GRADATION OF EXTRACTED AGGREGATE FOR RESULTS GIVEN IN TABLE VI

		Plant No. 3		Specific Gravity
Bin No. 1	Fine	55.0	Percent	2.629
Bin No. 2	Intermediate	30.0	Percent	2.637
Bin No. 3	Coarse	11.0	Percent	2.627
Mineral Filler	Limestone Dust	4.0	Percent	2.711
Asphalt Content	60-70 Penetration	5.5	Percent	1.030

Gradation of the Extracted Aggregate

U. S. Sieve	Percent Passing
3/4 inch	100.0
1/2 inch	89.0
3/8 inch	83.0
No. 4	61.0
No. 10	52.0
No. 40	32.0
No. 80	16.0
No. 200	7.0

TABLE XII

BIN PROPORTIONS AND GRADATION OF EXTRACTED AGGREGATE FOR RESULTS GIVEN IN TABLE VI

		Plant No. 4		Specific Gravity
Bin No. 1	Fine	50.0	Percent	2.648
Bin No. 2	Intermediate	30.0	Percent	2.653
Bin No. 3	Coarse	16.0	Percent	2.645
Mineral Filler	Limestone Dust	4.0	Percent	2.70
Asphalt Content	85-100 Penetration	5.7	Percent	0.99

Gradation of the Extracted Aggregate

U. S. Sieve	Percent Passing
3/4 inch	100.0
1/2 inch	98.0
3/8 inch	92.0
No. 4	76.0
No. 10	59.8
No. 40	33.5
No. 80	20.0
No. 200	6.5

TABLE XIII

BIN PROPORTIONS AND GRADATION OF EXTRACTED AGGREGATE FOR RESULTS GIVEN IN TABLE VI

		Plant No. 5		Specific Gravity
Bin No. 1	Fine	48.0	Percent	2.621
Bin No. 2	Intermediate	23.0	Percent	2.621
Bin No. 3	Coarse	26.0	Percent	2.605
Mineral Filler	Limestone Dust	3.0	Percent	2.686
Asphalt Content	85-100 Penetration	5.2	Percent	1.020

Gradation of the Extracted Aggregate

U. S. Sieve	Percent Passing
3/4 inch	100.0
1/2 inch	97.0
3/8 inch	--
No. 4	68.0
No. 10	54.0
No. 40	28.0
No. 80	13.0
No. 200	6.0

TABLE XIV

BIN PROPORTIONS AND GRADATION OF EXTRACTED AGGREGATE FOR RESULTS GIVEN IN TABLE VI

		Plant No. 6		Specific Gravity
Bin No. 1	Fine	42.0	Percent	2.642
Bin No. 2	Intermediate	9.0	Percent	2.626
Bin No. 3	Medium	33.0	Percent	2.609
Bin No. 4	Coarse	13.0	Percent	2.605
Mineral Filler	Limestone Dust	3.0	Percent	2.686
Asphalt Content	85-100 Penetration	5.0	Percent	1.020

Gradation of the Extracted Aggregate

U. S. Sieve	Percent Passing
3/4 inch	100.0
1/2 inch	94.0
3/8 inch	--
No. 4	65.0
No. 10	53.0
No. 40	26.0
No. 80	12.0
No. 200	5.0

TABLE XV

BIN PROPORTION AND THEORETICAL GRADATION OF AGGREGATE FOR COOPERATIVE TEST NO. 1

				Specific Gravity
Bin No. 1	Fine	58.0	Percent	2.644
Bin No. 2	Intermediate	25.0	Percent	2.632
Bin No. 3	Coarse	12.0	Percent	2.627
Mineral Filler	Limestone Dust	5.0	Percent	2.864
Asphalt Content	85-100 Pen.	5.75	Percent	1.020

Gradation of Theoretical Gradation

U. S. Sieve	Percent Passing
1 inch	100.0
3/4 inch	99.7
1/2 inch	91.2
No. 4	63.7
No. 10	53.2
No. 40	36.4
No. 80	22.1
No. 200	13.8

TABLE XVI

BIN PROPORTIONS AND THEORETICAL GRADATION OF AGGREGATE FOR COOPERATIVE TEST NO. 2

				Specific Gravity
Bin No. 1	Fine	60.0	Percent	2.65
Bin No. 2	Intermediate	24.0	Percent	2.63
Bin No. 3	Coarse	12.0	Percent	2.60
Mineral Filler	Limestone Dust	4.0	Percent	2.71
Asphalt Content	85-100 Pen.	5.5	Percent	1.020

Theoretical Gradation

U. S. Sieve	Percent Passing
3/4 inch	100.0
1/2 inch	95.2
No. 4	69.4
No. 10	58.9
No. 40	31.1
No. 80	14.5
No. 200	9.5

Method of Test for

APPARENT SPECIFIC GRAVITY OF COARSE AGGREGATE FOR BITUMINOUS MIXTURES

LDH DESIGNATION: TR–300-57

Scope

1. This method of test is intended for determining the apparent specific gravity of coarse aggregate for use in bituminous mixtures. This method should be used for coarse aggregate showing water absorption of less than 2.5%, namely the specific gravity of gravel and crushed stone will be tested by this method.

Aggregate showing a water absorption greater than 2.5% will be tested by use of LDH Designation: TR 302, "Method of Test for the Bulk Impregnated Specific Gravity of Combined Aggregate for Bituminous Mixtures".

Apparatus

2. The apparatus shall consist of the following:

(a) *Balance* – A balance having a capacity of 2 Kilograms or more and sensitive to 0.1 gram or less. (Dunnagan Bouyancy Apparatus manufactured by Humbold Manufacturing Company is suitable for this purpose.)

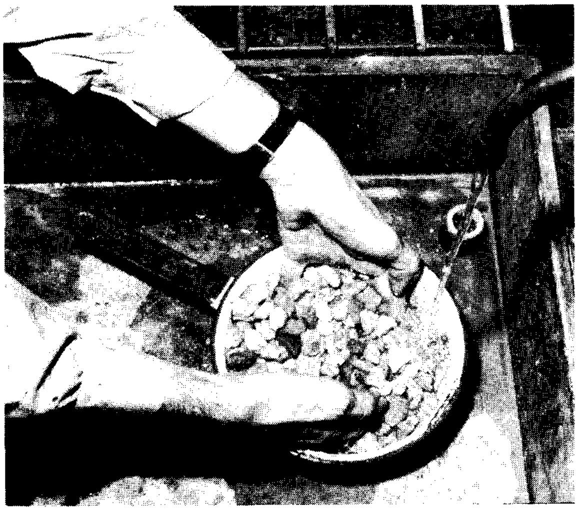


FIGURE I

Washing Sample of Coarse Aggregate for Specific Gravity

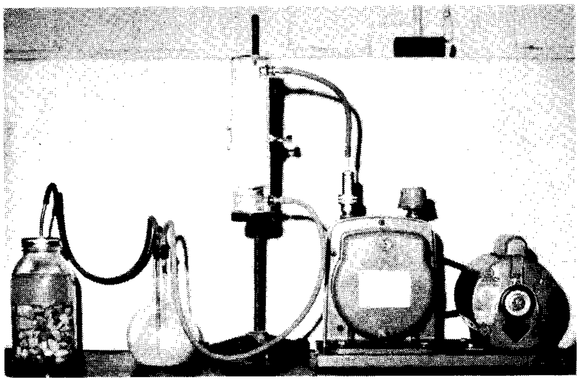


FIGURE II

Coarse Aggregate Under Vacuum

Sample

3. The samples shall be prepared in the following manner:

(a) *Stockpile Samples* – Stockpile samples of the coarse aggregate will be screened through a No. 4 mesh sieve and if the material passing this sieve is more than 5% the specific gravity of this fraction will be determined by use of the LDH Designation: TR 301, "Method of Test for the Apparent Specific Gravity of Fine Aggregate and Mineral Filler for Bituminous Mixtures". The fraction retained on a No. 4 mesh sieve will be tested by the methods explained under Section 4.

(b) *Bin Samples* – The specific gravity will be determined for each bin. The gravity of the fine bin (generally Bin No. 1) will be determined by use of LDH Designation: TR 301.

Procedure

4. (a) Approximately 1 to 2 Kilograms of the aggregate shall be selected from the sample to be tested by the method of quartering. In no event shall a predetermined weight be used.

(b) After thoroughly washing to remove dust or other coatings from the surface of the particles, the sample shall be immersed in water for 24 hours.

(c) The sample will then be transferred into a Mason jar (2 quart capacity) or another suitable container. The jar will be filled with water and attached to a vacuum for 15 to 30 minutes.

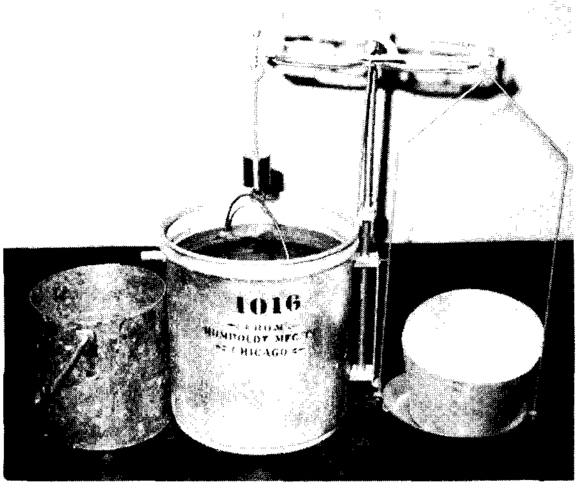


FIGURE III

Dunnagan Apparatus for Weighing Sampler in Water

(d) When this step is completed the sample will be placed in the weighing bucket, previously filled with water, and stirred for 30 seconds by use of a spatula to eliminate the presence of any trapped air bubbles.

(e) The weighing bucket will then be placed in testing position and the weight of the sample, under water, be determined.

(f) The sample shall then be dried to constant weight at a temperature of 100 to 110°C, cooled to room temperature, and weighed in air.

(g) The apparent specific gravity should then be calculated by use of the following formula:

$$\text{Apparent Specific Gravity} = \frac{A}{A-B}$$

where:

A = weight in air
B = weight in water

References:

AASHO Designation T 85–45
ASTM Designation C 127–42

Method of Test for

APPARENT SPECIFIC GRAVITY OF FINE AGGREGATE AND MINERAL FILLER FOR BITUMINOUS MIXTURES

LDH DESIGNATION: TR-301-57

Scope

1. This method is intended for the determination of the apparent specific gravity of mineral filler and fine aggregate (fraction passing a No. 4 mesh sieve) for use in bituminous mixtures showing a water absorption of less than 2.5%. Whenever the aggregate shows an absorption greater than 2.5%, LDH Designation: TR 302, "Method of Test for the Bulk Impregnated Specific Gravity of Combined Aggregate", will be used.

Apparatus

2. The apparatus shall consist of the following:

(a) *Balance* – A balance having a capacity of 1 Kilogram or more and sensitive to 0.1 gram or less.

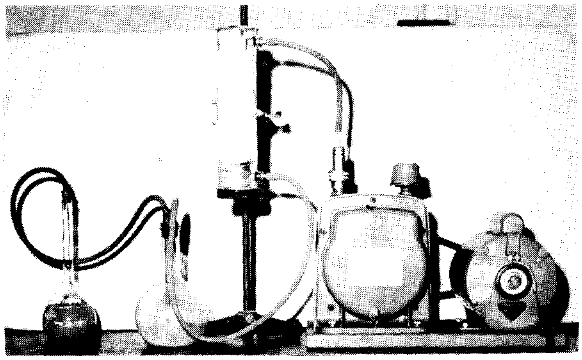


FIGURE I

Fine Aggregate Under Vacuum

(b) *Flask* – A volumetric flask of 500 milliliter capacity, calibrated to 0.15 milliliters at 77°F (25°C).

Procedure

3. (a) 1000 gram portion of the fine aggregate will be placed in a suitable container and dried to constant weight at 100 – 110°C.

(b) The sample will then be cooled to room temperature and 200 – 300 grams portion will be obtained by quartering and poured into the tared volumetric flask (100 – 125 grams should be used for mineral fillers).

(c) The flask and contents will be weighed and the flask filled with water to a level approximately 1 inch above the surface of the fine aggregate.

(d) The flask will be left at room temperature for 24 hours. After this time it will be placed under vacuum for 15 – 30 minutes.

(e) The water level will be brought to slightly above the calibration mark and placed in a water bath at 77°F (25°C) for 1 hour.

(f) Then the water level will be adjusted so that the bottom of the meniscus will be at the same level with the calibration line.

(g) The flask and contents will be weighed and the weight recorded.

(h) The apparent specific gravity will be computed by use of the following formula:

$$\text{Apparent Specific Gravity} = \frac{A - B}{D - C + A}$$

where:

A = Weight of flask plus dry sample in grams
B = weight of flask in grams
C = weight of flask plus sample plus water in grams
D = calibrated volume of flask at 77°F (25°C)

Precautions:

500 milliliters volumetric flasks are generally calibrated at 60°F, therefore, they should be recalibrated at 77°F.

References:

AASHO Designation: T 84–45
ASTM Designation: C 128–42.

Method of

PREPARATION OF HOT MIX SAMPLES FOR MIX DESIGN

LDH DESIGNATION: TR–303-58

Scope

1. This method is intended for the proportioning and preparation of hot mix asphaltic concrete samples for mix design purposes. The Mixtures prepared by use of this method will be compacted and tested in accordance with "Method of Test for Determination of Specific Gravity of Compressed Bituminous Mixtures" LDH Designation: TR–304 and "Method of Test for the Stability and Flow of Asphaltic Concrete Mixtures – Marshall Method" LDH Designation TR-305.

Apparatus

2. (a) Constant temperature electric oven, capable of maintaining temperatures within ± 5°F.

(b) Balance – having a capacity of approximately 2 kilograms or more and sensitive to 1 gram or less.

(c) Sufficient number of pots, pans, etc.

(d) Other appurtenant equipment such as a dial thermometer, gloves, etc.

Preparation of Aggregate

3. (a) *Aggregate Samples from Bins* – represents aggregates which are ready to go into the pugmill. Therefore they should be tested in as near a received condition as possible. Particular attention should be paid to the dust coatings on the aggregate. In no event should this coating be removed.

(b) *Stockpile Samples* – If lumps are present in the stockpile samples of fine sand they should be broken up prior to weighing the aggregate.

Mechanical Analysis of the Aggregate

4. The sieve analysis of the aggregate will be run using the sieves specified in the specifications for the type of mixture called for on the plans or in the contract. The following test methods will be used for this purpose:

Coarse Aggregate LDH Designation: TR-101
Fine Aggregate LDH Designation: TR-101
Mineral Filler LDH Designation: TR-102

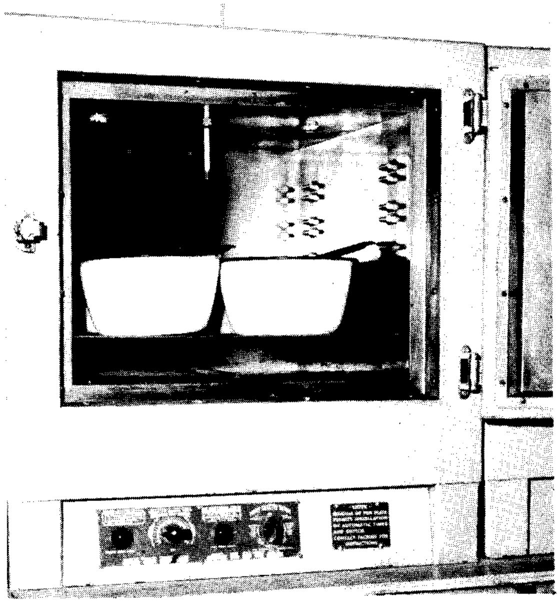


FIGURE I

Aggregate to be Heated to Proper Mixing Temperature

Computation of the Batch Weights

5. (a) Using the sieve analysis of the samples, different fractions are combined by trial and error method until a satisfactory gradation is obtained. The composite gradation should be safely within the specification limits called for in the contract and possibly at the approximate midpoint of the gradation requirements. Designing to a smooth curve is desirable but not always essential. The primary objective is to produce the best possible grading within the specification limits with the available materials.

(b) In designing an asphaltic concrete mixture it is necessary to compare a number of asphalt contents and select the most suitable one. A minimum of three different asphalt contents should be tried at 0.5% increments. Specifications require that, exact limits be set for each size of aggregate and asphalt and that they add up to 100.0% of total mixture. In other words, an asphalt content of 5.5% means that the total mixture is composed of 94.5% aggregate and 5.5% asphalt. However, recommendations are made as based on 100% of aggregate.

Therefore, the batch weights are computed for each one of the asphalt contents as based on 100% of total mixture including the asphalt (Form 3018 will be used for this purpose). Each batch will consist of the required quantity of mixture (asphalt and aggregate) to give a compacted briquette 2-1/2 ± 1/8 inches in thickness (regular gravel mixtures require 1200 grams for a thickness of 2-1/2 inches). All briquettes that are not within ± 1/8 inch of 2-1/2 inches will be *discarded.*

(c) A minimum of three samples (briquettes) will be prepared and tested at each asphalt content.

Procedure

6. (a) The aggregates shall be thoroughly dried prior to weighing. In preparation of the aggregate the most important factor is uniformity in gradation. In order to eliminate any possible segregation, extreme care should be exercised. The aggregate must be scooped to the bottom of the container when removing for weighing purposes.

(b) Then the aggregate is weighed dry, mixed and heated to the temperature specified in Table I.

TABLE I

Asphalt to be used	Temp. of Asphalt	Temp. of Aggregate
60-70 pen. (AC-3)	325°F ± 5°F	350°F ± 5°F
85-100 pen. (AC-5)	300°F ± 5°F	325°F ± 5°F

It takes approximately 3 hours for the aggregate to get to the specified temperature in the oven.

(c) Approximately 30 minutes prior to starting the mixing operations the asphalt will be heated on a Bunsen burner with an asbestos wire mesh to the specified temperature in Table I. Prolonged heating hardens the asphalt producing erratic results. Therefore, it should not be kept at this temperature for over one (1) hour.

(d) A crater is then formed in the aggregate and the necessary amount of asphalt at the specified temperature is weighed into the crater. The asphalt prior to weighing should be within ± 5°F of the specified temperature.

(e) Mixing should be accomplished immediately after the introduction of the asphalt. The time elapsing from the instant the aggregate is taken out of the oven to the first blow of the hammer must not be over *three (3) minutes.* As soon as a uniform distribution of the asphalt is obtained, the briquettes are made and tested as described in "Method of Test for Stability and Flow of Asphaltic Concrete Mixtures – Marshall Method" LDH Designation: TR-305 and "Method of Test for the Specific Gravity of Compressed Bituminous Mixtures" LDH Designation: TR-304.

(f) For all mix design purposes a minimum of three (3) briquettes will be prepared and tested. The test values for all test specimens of a given asphalt content will be averaged. Values obviously in error shall not be included in the average. The average test properties for Percentage of Theoretical Gravity, Density, Percent Voids—Total Mix, Percent Voids Filled with Asphalt, Stability at 140°F and Flow – 1/100 inch will be plotted versus the asphalt content and smooth curves will be drawn connecting these points.

Selection of the Optimum Asphalt Content

7. (a) Practice has indicated that the selection of the optimum asphalt content is the most important factor in the design of bituminous mixtures.

The optimum asphalt content is selected from the curves of the test properties as the average of the asphalt contents corresponding to the midpoint of the specification requirements for *% Voids – Total Mix, Percent Voids Filled with Asphalt* and the maximum points on the curves for the *Density – lbs./cu.ft.* and *Stability* values. The asphalt contents on each respective curve corresponding to the preceding values will be averaged and reported as the "optimum asphalt content" provided all the test properties meet the Design Criteria given in the specifications for the specified type of mix at this asphalt content.

(b) Under no circumstances will an optimum asphalt content be recommended whenever any one or more of the properties given in paragraph 7 (a) do not meet the requirements.

Method of Test for

DETERMINATION OF SPECIFIC GRAVITY OF COMPRESSED BITUMINOUS MIXTURES

LDH DESIGNATION: TR-304-58

Scope

1. This method of test is intended to determine the bulk specific gravity of specimens of compressed bituminous mixtures. This is a modification of AASHO Designation: T-166 (ASTM Designation: D-1188). This method is to be used by the District and Central Laboratories.

Apparatus

2. (a) For laboratory made specimens, namely *briquettes*, the apparatus will consist of the following:

(1) A balance having a capacity of 2 kilograms or more and sensitive to 0.1 gram.

(2) A wire basket of No. 4 mesh or some other suitable device for holding the specimen.

(3) Container with overflow device for immersing the wire basket in water and maintaining a constant water level.

(4) Suspension apparatus for suspending the wire basket from center of scale pan.

(b) For samples taken from the pavement, namely *roadway samples*, the apparatus will consist of the following:

(1) Balance having a capacity of 5 kilograms or more and sensitive to 1 gram.

(2) A wire basket, container with overflow device, and suspension apparatus conforming to the requirements given in Section 2 (a) items (2) through (4).

Samples

3. (a) Samples of mixture made with aggregates of low absorption or dense grade mixtures such as regular wearing and binder course mixtures will be tested *without* paraffin coating.

(b) Samples prepared with highly absorptive aggregates such as light-weight aggregate or shell, and specimens of open graded mixtures will be tested *with* paraffin coating.

Procedure Without Paraffin Coating

4. (a) The specimens, after they have stayed in air at room temperature for one hour, will be weighed in air. Laboratory prepared samples (briquettes) will be weighed to the closest 0.1 gram whereas the roadway samples will be weighed to the closest 1 gram.

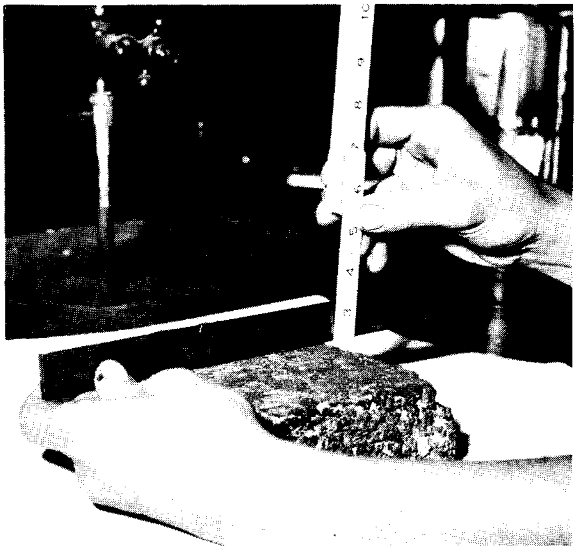


FIGURE I

(b) The specimens will then be placed on the wire basket and immersed in water and weighed. When weighing the samples in water extreme care should be taken to remove all the air bubbles from the surface of the immersed briquette. *Balance should be checked prior to each weighing*. Briquettes will be weighed to the closest 0.1 gram whereas the roadway samples will be weighed to the closest 1 gram.

(c) The bulk specific gravity of *uncoated* samples will be computed by use of the following formula:

$$\text{Bulk Specific Gravity} = \frac{A}{A - B}$$

where:

A = weight in air in grams.
B = weight in water in grams.

Note: Briquettes being tested at a hot mix plant laboratory may be weighed to the closest gram.

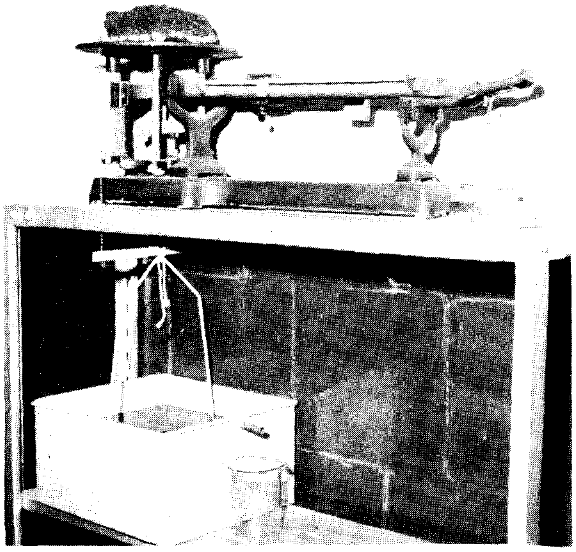


FIGURE II

Apparatus for Weighing Roadway Samples in Air and in Water

Procedure with Paraffin Coating

5. (a) After samples have stayed in air at room temperature for one hour they will be weighed as explained in Section 4 (a).

(b) The samples will then be coated with paraffin. The paraffin should be heated to 120°F prior to coating. This temperature gives the most desirable form of coating which is very easy to remove after the test. Care should be taken to eliminate the presence of air pockets in the paraffin coating.

(c) The coated samples will be cooled to room temperature and then weighed in air as explained in Section 4 (a).

(d) The coated samples will then be weighed in water as explained in Section 4 (b).

(e) The bulk specific gravity of *coated* samples will be computed by use of the following formula:

$$\text{Bulk Specific Gravity} = \frac{A}{D - E - \frac{(D - A)}{F}}$$

where:

A = weight in grams of the dry uncoated specimen in air.
D = weight in grams of the dry specimen plus paraffin coating in air.
E = weight in grams of the dry specimen plus paraffin coating in water.
F = bulk specific gravity of the paraffin. (1)

(1) Whenever the actual specific gravity of paraffin is not available 0.9 can be used for this purpose.

(f) After the test is completed the paraffin coating should be removed from the briquettes if they are to be tested for stability. This can easily be accomplished by immersing the specimens in water at 120°F for a few seconds and scraping the paraffin off by use of a spatula.

Reproducibility

6. Duplicate determinations shall check to within *0.02* in the case of roadway samples and to within *0.01* for laboratory samples or briquettes.

Report

7. The report shall include:
   (a) For Briquettes:
      (1) Specific Gravity
      (2) Theoretical Gravity
      (3) Percent Theoretical Gravity
      (4) Density – lbs. per cubic foot
      (5) Percent Voids in Total Mixture

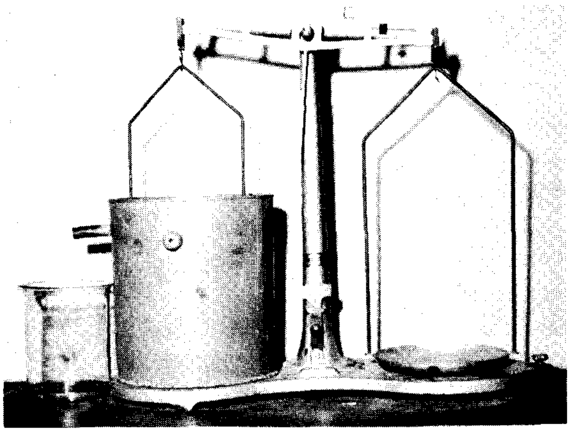


FIGURE III

Apparatus for Weighing Briquettes in Water

(6) Percent Voids Filled with Asphalt
(7) Stability – lbs. @ 140°F
(8) Flow – 1/100 inch

(b) *For Roadway Samples:*
(1) Specific Gravity
(2) Theoretical Gravity
(3) Percent Theoretical Gravity
(4) Average Briquette Specific Gravity
(5) Percent Laboratory Briquette Gravity
(6) Thickness in inches

Calculations

8. (a) *Percent of Theoretical Gravity* will be computed by use of the following formula:

$$\% \text{ Theoretical Gravity (F)} = \frac{D \times 100}{E}$$

where:
D = specific gravity of briquette.
E = theoretical gravity of the mix.

(b) *Percent Voids – Total Mix* will be computed by use of the following formula:

$$\% \text{ Voids – Total Mix (H)} = 100 - F$$

where:
F = % theoretical gravity.

(c) *Density* will be computed as follows:

$$\text{Density (lbs./cu.ft.)} = D \times 62.4$$

where:
D = specific gravity of compacted mixture.

(d) *Percent Voids Filled with Asphalt (% V.F.A.)* will be computed by use of the following formula:

$$\% \text{ Asphalt by volume (I)} = \frac{D \times J}{K}$$

where:
D = specific gravity of mix.
J = percent asphalt in mix.
K = specific gravity of asphalt.

and

$$\% \text{ V. F. A.} = \frac{I}{H + I} \times 100$$

where:
I = % asphalt by volume.
H = % voids - total mix.

(e) *Percent of Laboratory Briquette Specific Gravity* will be computed by use of the following formula:

$$\% \text{ Laboratory Briquette Gravity} = \frac{P}{D} \times 100$$

where:
P = the specific gravity of roadway sample.
D = average specific gravity of briquettes for the same days run.

Method of Test for

THE STABILITY AND FLOW OF ASPHALTIC CONCRETE MIXTURES – MARSHALL METHOD

LDH DESIGNATION: TR–305-58

Scope

1. This method is commonly known as the "Marshall Method". It is intended in this method to determine the physical characteristics of asphaltic concrete or sand asphalt mixtures regarding the stability and flow.

Apparatus

2. (a) Marshall Testing Machine
   (b) Marshall Hammer
   (c) Compaction Pedestal (see Figure 1)
   (d) Compaction Mold Holder
   (e) Two (2) Compaction Molds
   (f) Stability Test Mold
   (g) Flow meter with 1/100 inch divisions
   (h) Hot water bath
   (i) Dial thermometer, 50-500°F, 5°F divisions
   (j) Bath thermometer, 30-180°F, 1°F divisions
   (k) Mixing spoon, scoop, containers, etc.

Samples

3. (a) *Samples mixed at a Hot Mix Plant*– When sampling a bituminous mixture, extreme care should be taken to obtain a truly representative sample of the material to be tested.

A composite sample shall be taken, portions of which shall come from the top, front and back of the load.

Immediately after sampling the temperature of the mix shall be taken and recorded.

(b) *Laboratory Prepared Samples*– For mix design purposes the mixture will be prepared as specified in "Method of Preparation of Hot Mix Samples for Mix Design" LDH Designation: TR–303.

Preparation of Test Specimens

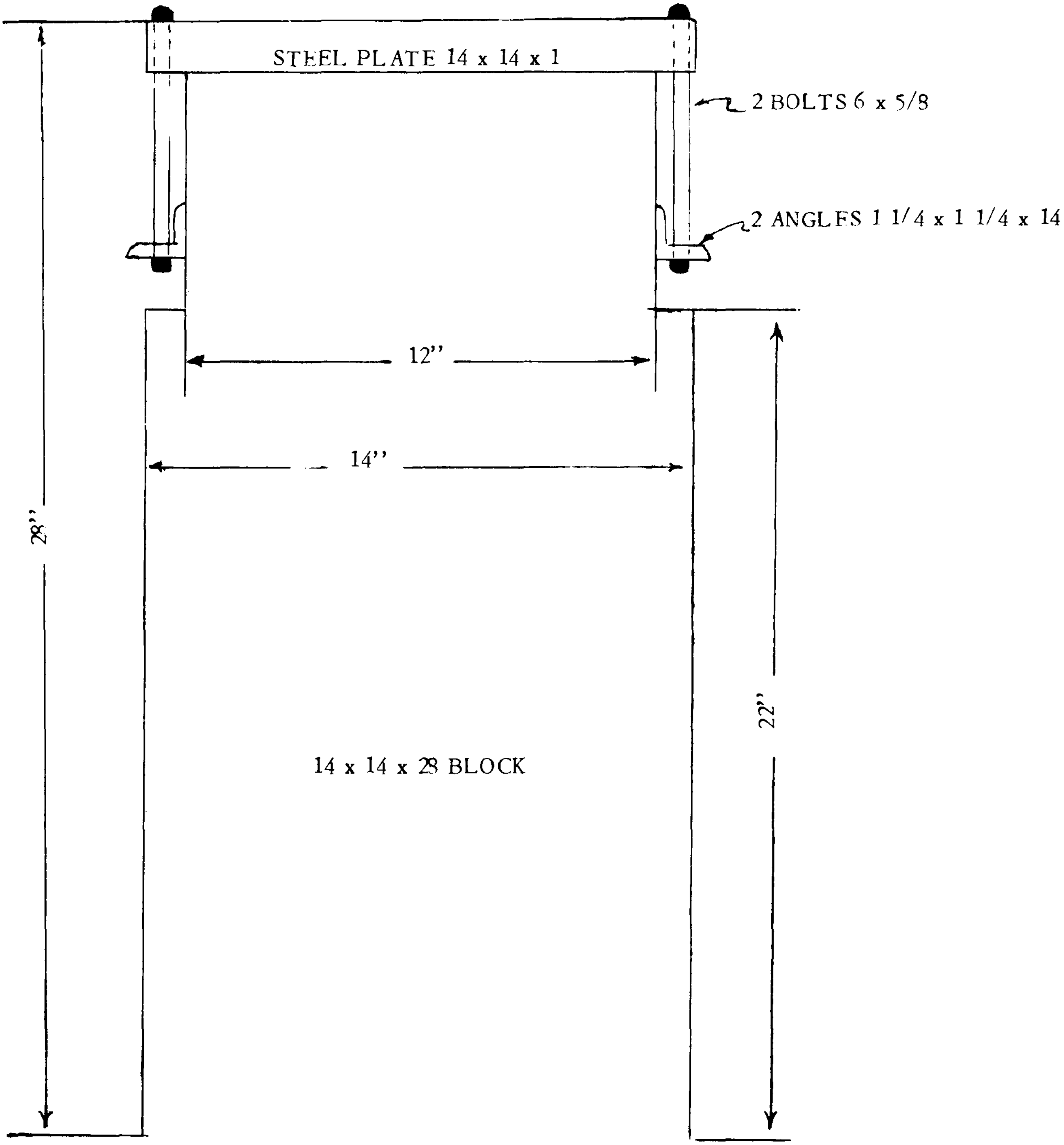
4. (a) Prior to molding specimens, the molds will be placed in the water bath at 140°F ± 1°F for 5 minutes. This includes the base plate, the mold and the collar. This step should be accomplished prior to sampling in order to prevent the mixture from cooling. As soon as the mixture is ready to be compacted the mold will be taken out of the bath placed on the compaction pedestal and fastened tightly by means of the mold holder and the inside will be dried by use of a dry rag and a *light* application of kerosene made on the inside.

(b) The sample shall be transferred into the mold immediately after mixing. Losing too much time would cause the mix to cool and the necessary compaction cannot be secured. Prior to compaction, the temperature of the mix shall not be less than 275°F. The mixture shall be scooped to the bottom each time, to prevent segregation of fine and coarse aggregates. After the mold is filled with the necessary amount of mixture to make a briquette 2-1/2 ± 1/8 inches thick, (1150-1200 grams) the material shall be rodded exactly twenty-five times by use of a spoon to secure a uniform placement. The surface of the mixture shall be smoothened to a slightly rounded shape with the spoon.

(c) The sample will then be compacted by fifty blows of the compaction hammer. Extreme care should be taken in counting the number of the blows as most of the properties of the mixture is highly dependent on the degree of compaction applied. It is very important that the compaction pedestal used be in accordance with the requirements shown in Figure 1.

Application of a light coating of

STANDARD BLOCK FOR MARSHALL HAMMERS



NOTE: All Marshall Hammers used in the field or in the Laboratory should be equipped with this pedestal.

kerosene to the base of the hammer will help to prevent the sticking of the hammer to the surface of the briquette.

(d) The base plate and collar shall be removed, and the mold turned over and reassembled. Fifty blows shall then be applied to this side of the briquette. The base of the hammer should be cleaned by use of a rag dampened with kerosene prior to compaction, as in the first case.

(e) After compaction the base plate and mold shall be removed and the mold and contents shall be placed in a cool water bath until the material has cooled to room temperature.

(f) After the specimen has cooled, the mold shall be placed over the upper section of the collar resting on the compaction base. The specimen will then be forced out by a few light blows of the hammer into the collar which is of larger diameter.

(g) The specimens shall be 2-1/2" ± 1/8" in height, all those that do not meet this requirement shall be *discarded.*

FIGURE I

Test for Specific Gravity and Computation of Density Characteristics

5. The specific gravities of the briquettes will be determined by use of "Method of Test for Determination of Specific Gravity of Compressed Bituminous Mixtures" LDH Designation: TR–304 and the density characteristics will be determined as explained therein.

Test for Stability and Flow

6. (a) After all the density characteristics have been computed the specimens will be tested for stability and flow at 140°F plus or minus 1°F. The briquettes and the *testing mold* will be placed in a hot water bath for *twenty* (20) minutes. When placing the specimens in the bath care should be taken to place them at least one inch apart. In no event should the specimen touch the side or the bottom of the water bath or the thermometer.

(b) The inside surface of the testing mold and the guide rods shall be cleaned thoroughly, prior to testing and the guide rods shall be well lubricated so that the upper part of the test mold can move freely.

(c) The testing mold and the specimen shall be removed from the water bath, placed in testing position with the upper part of the testing mold placed on the specimen and the complete assembly shall be transferred to the platform of the testing machine. The flow meter will then be placed on one of the guide rods and set to zero. Extreme care should be exercised to make sure that the movable "inner rod" in the flow meter is pulled out as far as it will go prior to placing the meter in testing position in order to insure a contact with the guide rod. Load shall then be applied to the specimen. During the application of the load, the flow meter should be held firmly against the top of the upper part of the testing mold. When the maximum load is reached on the stability dial, the flow meter shall instantly be released. It is very important that the flow meter be released upon reaching the failure point on the stability dial, because after failure even though the motor is stopped there is a continuous flow. The dial reading and the flow values shall be recorded.

LOUISIANA DEPARTMENT OF HIGHWAYS
TESTING & RESEARCH SECTION
STABILITY CORRELATION RATIO
For Marshall Method

Revised September, 1958

Volume of Specimen in Cubic Centimeters	Approximate Thickness of Specimen in Inches	Correlation Ratio
200 – 213	1	0.18
214 – 225	1-1/16	0.20
226 – 237	1-1/8	0.22
238 – 250	1-3/16	0.24
251 – 264	1-1/4	0.26
265 – 276	1-5/16	0.28
277 – 289	1-3/8	0.30
290 – 301	1-7/16	0.33
302 – 316	1-1/2	0.36
317 – 328	1-9/16	0.40
329 – 340	1-5/8	0.44
341 – 353	1-11/16	0.48
354 – 367	1-3/4	0.52
368 – 379	1-13/16	0.56
380 – 392	1-7/8	0.60
393 – 405	1-15/16	0.64
406 – 420	2	0.68
421 – 431	2-1/16	0.72
432 – 443	2-1/8	0.76
444 – 456	2-3/16	0.80
457 – 470	2-1/4	0.84
471 – 482	2-5/16	0.88
483 – 495	2-3/8	0.92
496 – 508	2-7/16	0.96
509 – 522	2-1/2	1.00
523 – 535	2-9/16	1.04
536 – 546	2-5/8	1.08
547 – 559	2-11/16	1.12
560 – 573	2-3/4	1.16
574 – 585	2-13/16	1.21
586 – 598	2-7/8	1.24
599 – 610	2-15/16	1.28
611 – 625	3	1.32

Notes:
1. The measured ability of a specimen divided by the ratio for the thickness of the specimen equals the corrected stability for a 2-1/2 inch specimen.
2. Volume-thickness relation is based on a specimen diameter of 4 in.

Since excessive cooling of the specimen causes an increase in stability and a decrease in the flow values, extreme rapidity of testing is necessary. The time that elapses between the removal of the specimen from the bath and the failure of the specimen should not be *over 30 seconds*. Whenever more than one briquette is being tested the

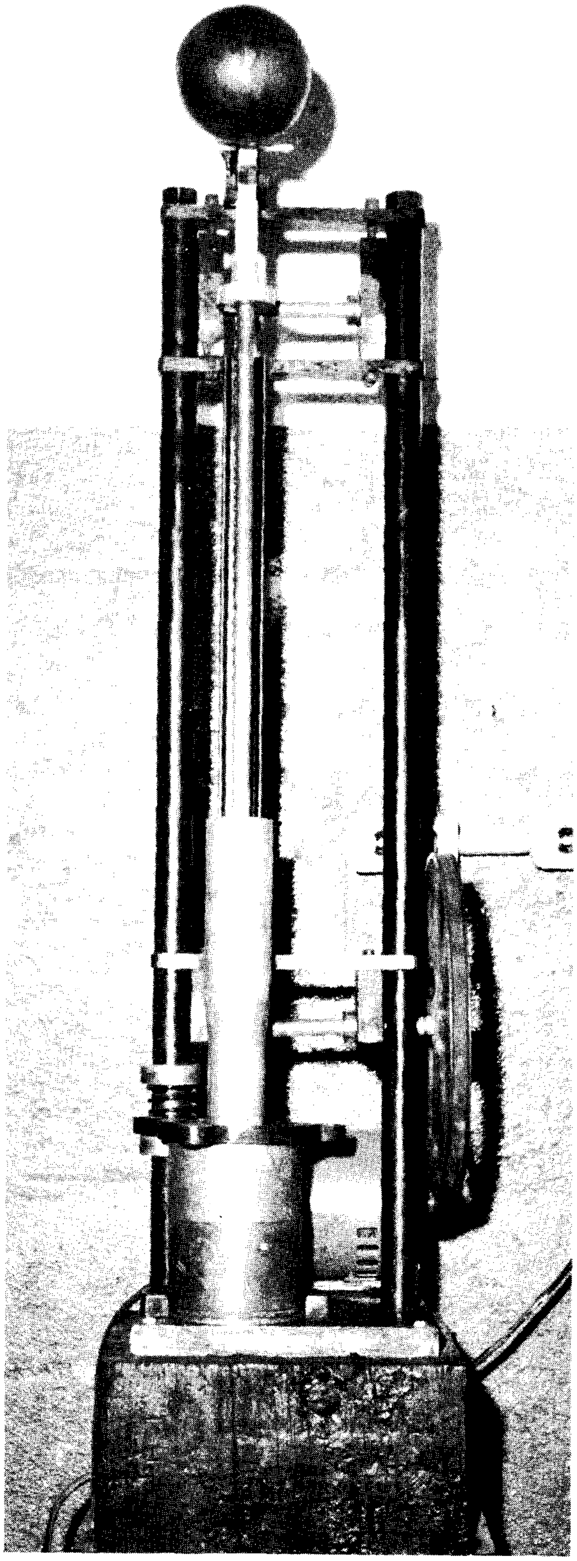


FIGURE II

Test Specimen Ready for Compaction

ACKNOWLEDGEMENTS

The study reported in this paper was performed by The Bituminous Research Unit of Louisiana Department of Highways. Tabulation of data, the statistical analyses and preparation of most of the discussion were done by Mr. S. C. Shah, Assistant Research Engineer.

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